OWidgets: a toolkit to enable smell-based experience design

Article (Accepted Version)

OWidgets: A Toolkit To Enable Smell-based Experience Design

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Abstract

Interactive technologies are transforming the ways in which people experience, interact and share information. Advances in technology have made it possible to generate real and virtual environments with breath-taking graphics and high-fidelity audio. However, without stimulating the other senses such as touch and smell, and even taste in some cases, such experiences feel hollow and fictitious; they lack realism. One of the main stumbling blocks for progress towards creating truly compelling multisensory experiences, is the lack of appropriate tools and guidance for designing beyond audio-visual applications. Here we focus particularly on the sense of smell and how smell-based design can be enabled to create novel user experiences. We present a design toolkit for smell (i.e., OWidgets). The toolkit consists of a graphical user interface and the underlying software framework. The framework uses two main components: a *Mapper* and *Scheduler* facilitating the device-independent replication of olfactory experiences. We discuss how our toolkit reduces the complexity of designing with smell and enables a creative exploration based on specific design features. We conclude by reflecting on future directions to extend the toolkit and integrate it into the wider audio-visual ecosystem.

Keywords: Smell, Olfactory Experiences, Design Toolkit for Smell, Smell-based Application Design, Software Framework for Smell, Smell-based Interaction Design.

1. Introduction

While there is a large body of knowledge on the sense of smell emerging from disciplines such as psychology, neuroscience, and sensory science, within the field of Human-Computer Interaction (HCI) we are still at an embryonic stage in finding the right approach for designing with smell. Contrary to our other senses where we have a basic agreed vocabulary to work with (e.g., colour names, RGB, hue, saturation, sound pitch, and volume), we do not have common reference points for the sense of smell. Moreover, we also lack concrete tools and frameworks to support the design of odour interfaces. In other words, other modalities like vision, hearing, and increasingly touch are supported with interaction techniques, design tools, and widgets. Such a support does not exist for the sense of smell.

Given the immediacy and ubiquity of taste and smell, not to mention their importance to health, safety, work, leisure, pleasure, and a persons sense of emotional wellbeing, future smell-based and multisensory experiences with interactive technologies could have a major impact on society and consumer markets, creating entirely new product, technology, and service opportunities. More importantly, multisensory experience research promises to deliver a step-change in our understanding of the human senses as interaction modalities and potentially also revolutionise existing interaction paradigms within the field of HCI.

Although the unique characteristics of the sense of smell are increasingly acknowledged within HCI (e.g., (Kaye, 2004, 2001; Kortum, 2008; Patnaik et al., 2019)) especially when designing VR experiences (Ranasinghe et al., 2018a), ambient notifications (Arroyo et al., 2002; Maggioni et al., 2018), new in-car interactions (Dmitrenko et al., 2017b,a, 2018; Wintersberger et al., 2019)), the community is missing out on a lot of opportunities for creating and improving smell-based interactions, beyond one-off applications.

Inspired by a tradition of toolkit development and research in HCI (see (Myers et al., 2000; Ledo et al., 2018)) we introduce in this paper OWidgets, a toolkit for smell-based experience design. Toolkits are generative platforms that provide easy access to complex algorithms, enable fast prototyping and creative explorations of design spaces. More specifically, a toolkit is a way to encapsulate interface design concepts and elements (e.g., widget sets, interface builders, development environments) that allow programmers and non-programmers to create interactive applications (Greenberg, 2007).

Our toolkit enables the creation and replication of olfactory experiences (OXs) (see Fig.1). By OXs we refer to the experience had by a person when perceiving a mixture or series of one or more scents, and to describe this experience we identified four measurable key design features (i.e., scent intensity, emotional reactions, scent-associations, spatial information). Our toolkit consists of two main parts: a graphical user interface (GUI), and the

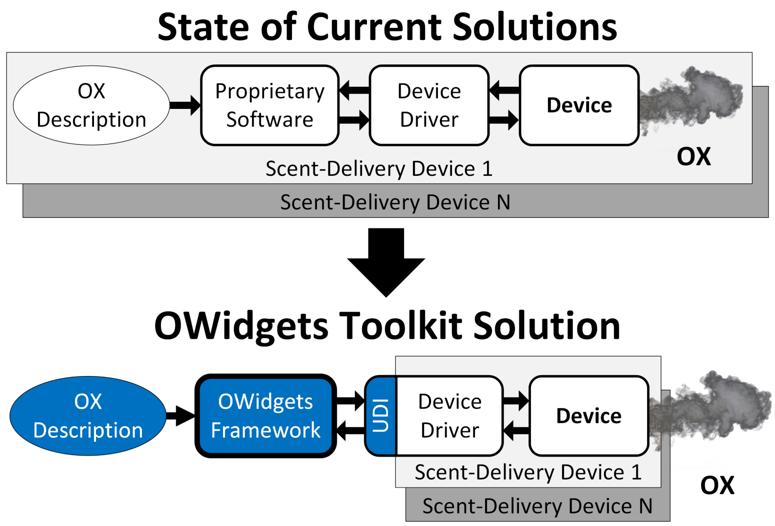

Figure 1: A schemata of the toolkit contribution. *Top*: State of the art of current solutions in which olfactory experience (OX) description, control, and delivery depend on the scent-delivery device used. *Bottom*: OWidgets toolkit standardising the description of OXs and facilitating replication across devices.

underlying software framework that facilitates device-independent OX design. The OWidgets GUI reduces the complexity of working with smell and enables the design of OXs through direct manipulation of four key design features, accounting for the capabilities of the scent-delivery device used. The OWidgets software framework supports the GUI and consists of two components: the *Mapper*, that is responsible for converting the designed OX into a set of device instructions, and the *Scheduler*, which manages the dispatching of the OX and resolves potential conflicts between different OXs. For device-independent OX design, our toolkit also includes a uniform device interface (UDI) to enable the communication between the software framework and whichever scent-delivery devices (SDDs) are available. The UDI is important as more and more SDDs are emerging on the consumer market without a standard method for control.

In summary, OWidgets as a toolkit aims to:

(i) Reduce the complexity of smell in the design of interactive systems;
(ii) Guide the design explorations based on design features;
(iii) Empower a variety of audiences (e.g., from developers, artists, and designers) to experiment and use smell in interactive systems;

(iv) Enable not just the creation but also replication of OXs independent of the available SDD.

Our paper contributes the first device-independent toolkit to enable the design of olfactory experiences (OXs).

2. Related Work

Smell is known to be the most complex and challenging human sense. In contrast to other human senses (e.g., primary colours in colour vision and basic tastes in taste perception), we likely cannot rely on a notion of primary smells. The lack of such a common reference point including a common vocabulary to talk about odour experiences, makes olfaction a risky sense to use in the design of interactive systems. Before we outline the details of the OWidgets toolkits development and associated challenges, we provide fundamental information on the functionalities of the sense of smell.

2.1. Fundamental Properties of the Sense of Smell

In its basic understanding, our sense of smell refers to the sensing of chemical molecules that exist in the environment. These molecules are called odorants (Yeshurun and Sobel, 2010) for simplicity we refer to them as odours or scents. Odours are a mixture of these volatile molecules (Bushdid et al., 2014; Yeshurun and Sobel, 2010). However, scent detection is only one part of an olfactory experience. The olfactory system completes the scent decoding process (i.e., sniffing action) by generating the appropriate internal representations in the brain, based on the associations related to the scent. In other words, scent-associated representations are based on a process of odour detection, decoding, and processing, which will ultimately define the users odour experience (Kay, 2011).

This process can either be based on a conscious perception of odour stimuli (e.g., I know there is the scent of coffee) or happen sub-consciously (e.g., I feel the need for a break but not consciously perceive the coffee scent). Even if we are not conscious of a scent in the air, it can still have a profound influence on our behaviour (Shepherd, 2004) (e.g., body odors (Frumin et al., 2015; Granqvist et al., 2019)). Sub-conscious stimulation is also referred to as under-threshold stimulation (Sobel et al., 2000).

Overall, chemical sensing and processing are very complex processes and still hold a lot of unanswered questions, which scientists in different disciplines investigate (from genetics to psychology (Keller, 2011; Keller and

Vosshall, 2004)). Moreover, we lack a mapping and translation of the complex scent properties into design features that can help guide design choices and ensure replicability of olfactory experiences. Here below we highlight the key challenges of designing with smell as basis for proposing a novel design toolkit for smell.

2.2. Challenges in the Design a Toolkit for Smell

Here we present a review of relevant work related to three key challenges which motivated the development of our toolkit for smell-based design. *Challenge 1 (C1)* refers to the limitations of existing software solutions for smell-based design. *Challenge 2 (C2)* highlights the impact of device choice when replicating OXs and thus the requirement for device-independent design. Finally, *Challenge 3 (C3)* is the lack of a common language around smell to describe OXs.

*2.2.1. Existing Solutions and Device Dependence (**C1** and **C2**)*

When trying to design using scent, we encountered our first challenge (*C1*): existing software solutions for controlling the scent delivery are simplistic, limited, and offer no design guidance. We reviewed the functionalities of the control software for the most promising commercial SDDs emerging on the consumer market, building on prior reviews (see (Dmitrenko et al., 2016; Risso et al., 2018)). We examined the software for three products: Scentee Machina[1], Cyrano[2], and AromaShooter[3]. The main functionalities allowed by the software of those devices are:

- The user can select the available scents from a list (Scentee Machina, AromaShooter, Cyrano);
- Switch on/off the scent delivery by cartridge index (Scentee Machina, AromaShooter, Cyrano);
- Deliver for a pre-defined duration (AromaShooter, Cyrano);
- Set and save the delivery parameters as an event (e.g., as an alarm on your phone — Scentee Machina) or in a timeline (AromaPlayer proprietary of AromaShooter).

[1]https://scentee-machina.com/
[2]https://onotes.com/
[3]https://aromajoin.com/

None of the devices' software allows for a comprehensive design of OXs, they are limited to delivering scents by cartridge index. The Scentee Machina software allows the user to adjust the intensity (called strength) of the delivered scents but offers no guide to designers for why or how they should use this feature. The AromaPlayer is the only software that lets the user schedule scent deliveries on a timeline and control multiple AromaShooter devices simultaneously. However, it provides no information on the perception of the OX (e.g., scent lingering, overlapping, or habituation).

Although we see a positive effort towards more control for individual devices through their proprietary software, there is, at the current time, no standard for programmatic control of SDDs, which restricts design of OXs to a specific device. These constraints in the control and use of smell, while understandable from a commercialization perspective (i.e., manufactures want to sell their own device), are limiting designers from exploiting the full potential of smell for their imagined smell-based application designs.

Moreover, available devices (both commercial and research prototypes) vary a lot in their capabilities (see Dmitrenko et al. (2016); Risso et al. (2018)). This variability impacts the experiences that we can design for. As a result, replicating the same experience using two different devices is a challenge (*C2*) in itself. A parallelism can be drawn to visual design and the challenge to ensure a printed image matches the colours displayed on a screen when the printer and screen have different colour gamuts (e.g., RGB or CMYK). However it is not only important to find a common language between devices, but to also establish a common vocabulary for designers when creating OXs.

*2.2.2. Lack of a Common Language to describe OXs (**C3**)*

Contrary to our other senses where we have a basic agreed vocabulary to work with (e.g., colour descriptors, RGB, hue, saturation), we lack such a common language for smell. Hence, the third challenge (*C3*) we faced was this absence of a language to describe scent-based experiences.

To talk about and describe smell we first need to define the meaning of OXs. Starting from the basics, we need to understand that scents are a mixture of chemical components which influence humans through a combination between the properties of the chemical components and the properties of their perceptual effects (Kay, 2011; Bushdid et al., 2014). These effects can be abstracted, for instance, the scent of burning (i.e., detection of chemicals) activates the mental representation of something burning (i.e., decoding meaning from scent) in the brain and thus informs us of potential danger (e.g., emotional reaction of fear) (Firestein, 2001; Kay, 2011; Yeshurun and Sobel, 2010; Auffarth, 2013). These scent-associated mental representations — based on chemical and perceptual features — are what we can define as an OX.

Furthermore, we also need to define what scents to use when designing OXs. There are prior attempts to describe and classify scents, however, they are limited and not widely adopted (Dravnieks, 1982; Koulakov et al., 2011). For instance, Dravnieks (1992) published an 'Atlas of Odor Character Profiles'— a collection of 146-attributes-list for a selection of 160 odorants (chemicals and mixtures) rated by 507 experts (sensory scientists). This scent-descriptors database has been found to be highly reliable and frequently employed as guidelines in scent classifications (e.g., (Mamlouk et al., 2003)). However, without accounting for perceptual and emotional effects this database alone is not enough to guide the design process in HCI.

More recently, Koulakov et al. (2011) analysed and characterised mono-molecular scent into a set of 146 perceptual descriptors in a multidimensional sensory space, obtained from odour character profiles. The results of this analysis, without eliminating the complexity related to human olfactory receptors, showed how these mono-molecular scents can be classified in a two-dimensional space related to physio-chemical properties, where one dimension represents the pleasantness or perceptual valence of the scents. The second dimension may be interpreted as a cross-modal correlation between scents and sound representations (e.g., lemon is high-pitch (Crisinel et al., 2013)). This multidimensional sensory space for classifying scents is an evolution compared to the 'Atlas of Odor Character Profiles', however it is limited to mono-molecular scents and so thus is not extendable into real-world contexts.

Although the above presented are attempts to describe scents, they are still limited to the chemical quality descriptors (Dravnieks, 1992), pleasantness and crossmodal attributes between sound and mono-molecular scents (Koulakov et al., 2011), which are limited to the needs in HCI, where we need to simplify the complexity with respect to experiential aspects (e.g., intensity or pleasantness of the scent stimuli).

3. Requirements for a Toolkit for Smell

Based on the above three main challenges and attempts to quantify smell-based design, we identified the following key requirements for an olfactory design toolkit: (1) a solution that allows device independent control and design of OXs (*C2*), (2) define the features to quantify and replicate OXs thus (3) provide the users with a common language to describe OXs and simplify the design with a level of abstraction (e.g., guiding the design through scents property features).

Moreover, designing for OXs will also need to account for individual differences (e.g., experiences determined by prior exposure to scents, scent-related memories, personal preferences and perceptual sensitivity) and thus needs to enable the creation of user profiles (Ghinea and Ademoye, 2010, 2012; Murray et al., 2016; Firestein, 2001). However most importantly, as a first step, it is necessary to establish a common vocabulary to describe OXs.

4. Common Language for OX Design

To create a common language for the quantification of an OX and scent selection, we identified a set of measurable features (i.e., Intensity, Emotions, Associations, and Spatial) (*see section OWidgets Toolkit - GUI*). Here we propose an initial scent mapping database following prior efforts towards measurable features (Chrea et al., 2008).

We performed a user study measuring the perceived intensity and emotional effects for a set of 12 scents (i.e., black pepper, cedarwood, eucalyptus, juniper, lemon, lavender, patchouli, peppermint, pine, rose, vanilla, ylang-ylang). Those scents were selected as they represent a first spectrum of scents with two-dimensional emotional effects (as suggested by previous work, see Dravnieks et al. (1984); Herz and Cupchik (1992); Distel and Hudson (2001); He et al. (2016); Bensafi et al. (2002a); Bestgen et al. (2015)). Moreover, those scents are commonly available on the market, as off-the shelf natural essential oils. The scents were presented to each participant using 10ml glass bottles, each containing 100% pure essential oil from Holland & Barrett Int. Ltd. All the bottles were covered with black tape to avoid any potential influence or bias due to the colours of each scent. To avoid further potential perceptual bias we also kept the bottle weights constant for all scents.

Participants were instructed to smell each scent, one at a time, and then rate each scent on three self-report questions, printed on a paper using a

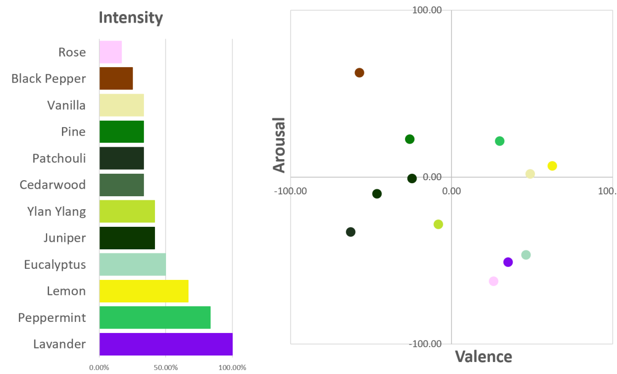

Figure 2: Two graphs showing our initial scent database. *Left*: A bar chart mapping the perceived intensity. *Right*: A two dimensional emotional mapping of each scent (valence on X-axis and arousal on Y-axis).

pen. For valence (pleasant-unpleasant) and arousal (calming-arousing) we asked participants to rate each scent on a 9-point Likert scale using the self-assessment manikin (SAM) (Bradley and Lang, 1994). Those ratings provided an overview on the emotional effect of each scent in a two-dimensional design space (see Fig.2). The third self-report question was capturing the participants' perceived intensity on a 9-point Likert scale ('not intense at all' to 'very intense') for each scent. We collected responses from 113 participants (38 females, *Mage*= 37, *SD*= 14). Based on the results we created an initial scent database (shown in Fig.2) that was integrated in our toolkit design (see Fig.3) and enables toolkit users to describe their desired olfactory experience based on the specific scent characteristics. Our results are consistent with previous studies on scent perception (e.g., see Dravnieks et al. (1984); Herz and Cupchik (1992); Distel and Hudson (2001); He et al. (2016); Bensafi et al. (2002a); Bestgen et al. (2015)).

This database provides an initial set of measurable features that enable the quantification of OXs, a necessary step in the challenge of providing replicable experiences. Moreover, the dataset is an integrated part of the toolkit design, offering users to select their desired scents description based on the valence, arousal, and perceived intensity levels. For example, if designers aim to design an intense experience, they can easily decide, just by looking at the scent dataset, to select either lavender or peppermint. Depending if the experience should be calming or arousing they can narrow the choice down to lavender or peppermint respectively. Users of the toolkit don't need to know the properties of the scent but can just select and explore the various scent options (see Fig.3). This classification is based on empirical evidence, which makes it valid beyond designers best guesses and enables replication of OXs. The dataset can easily be extended with more scents and a large user sample in the future. Here, the scent dataset serves as a starting point and as initial input to demonstrate the toolkit functionalities and facilitate the OWidgets toolkit design.

5. OWidgets Toolkit - GUI

Our toolkit consists of two main parts: a graphical user interface (GUI) and the underlying software framework. Here we start presenting the GUI utilising ***4 key features*** for enabling OX design: Intensity, Emotions, Associations, and Spatial (see Fig.4, left column). These features were extracted from literature and knowledge established in psychology, neuroscience, and sensory science. In the following sections we describe each of these key features (i.e., Intensity, Emotions, Associations, and Spatial) and their relevance in our toolkit to enable OX design.

5.1. Timeline Approach

Before describing each of the four features, it is important to understand that OXs can, as with auditory experiences, exist in and can change with time. Therefore, similar to auditory design tools, we focused our design features in the toolkit around this concept utilising a timeline approach. To best visualise this timeline, the features are displayed on a graph with the x-axis representing time and, if applicable, the y-axis quantifying the feature. This can be seen clearly in the design features for intensity and emotions (see description below, and see Fig.4, design area for an example).

5.2. Intensity Feature

The intensity dimension of a scent is an important feature in OX design (Holland et al., 2005; Jones and Woskow, 1964) as it determines the perceivability of the experience. Regulating perceived intensity can also be used to modulate the salience of the other features or to provide an additional channel of information (e.g., using scent-association intensity to convey different levels of urgency (Maggioni et al., 2018; Dmitrenko et al., 2017b)).

The intensity design feature is a timeline graph with draggable nodes. This graph has time on the x-axis and intensity on the y-axis, and the desired

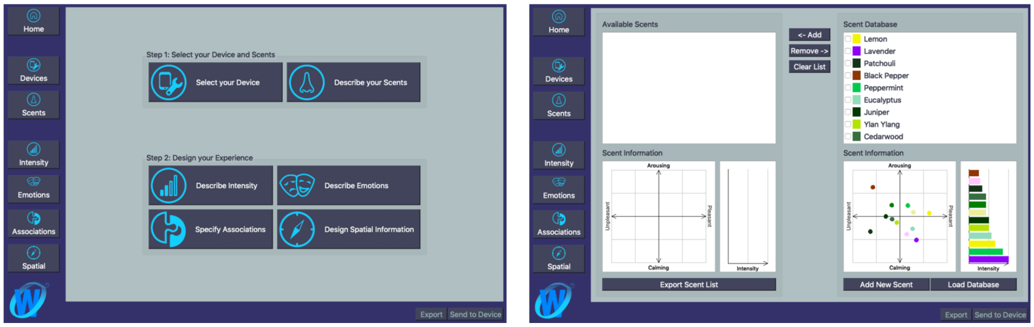

Figure 3: Main start page of the OWidgets toolkit GUI *left* and the scent dataset *right* to select the scents to describe the desired olfactory experience (OX) through exploring each scents valence, arousal, and intensity values (user study results reported in Section 4).

intensity experience is described by the x-positions and the heights of the nodes. As shown in Fig.4, the horizontal lines show the perceived intensities of the available scents, the desired intensity level is drawn as a dotted line, and an estimation of the actual perceived intensity level (using the available scents) is shown as a gradient-filled coloured area with the colour representing the scent used. This estimation (steepness of curve, height, and dispersion time) is based on the duration of the scent delivery and the properties of the SDD that the designer has specified (see *Scent-delivery Device Capabilities*).

The perceived intensity is controllable as it depends upon the concentration of the chemical components and their properties, the duration of the scent exposure, and habituation (Yeshurun and Sobel, 2010; Bensafi et al., 2002b; Ferdenzi et al., 2014). The perceived intensity can easily be modulated adjusting the scent concentration through various techniques (e.g., diluting with solvent) or by changing the chemical components (i.e., selecting another scent) (Jones and Woskow, 1964; Sobel et al., 2000). The perceived intensity can also be modified through adjusting the scent delivery parameters, such as delivering in pulses or by adjusting the distance between scent output and the user's nose.

The main design considerations regarding scent intensity is due to the habituation effect (i.e., scent adaptation) and the individual sensitivity (aka perceptual sensitivity) (Cain and Johnson Jr, 1978; Ferdenzi et al., 2014). Habituation causes a decrease in the olfactory perception due to prolonged exposure (Ferdenzi et al., 2014), and the magnitude of this habituation effect is correlated with the scent's chemical concentration, timing, and sequencing

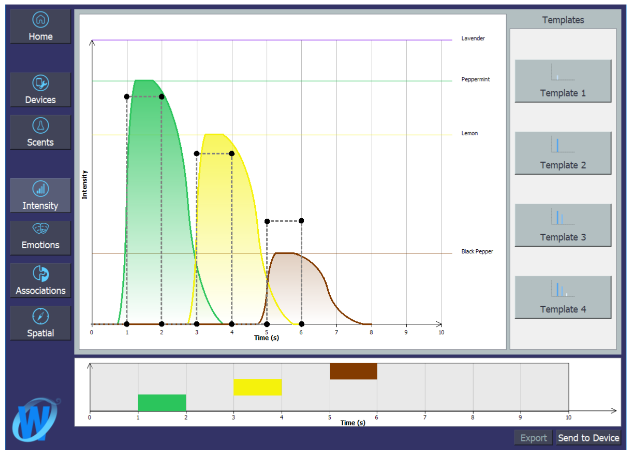

Figure 4: The GUI overview. *Left Column*: Navigation bar of the features 4 key design features (i.e., Intensity, Emotions, Associations, Spatial). *Middle* The feature design area of the Intensity feature with a timeline *Bottom*: The overview timeline. *Right*: The intensity design templates.

of the scents (e.g., alternating between different scents) (Croy et al., 2013; Cain, 1968). The individual sensitivities are linked with individual preferences and can be stored within the user's profile (see *User Profile*).

5.3. Emotions Feature

The ability of scents to elicit specific emotional reactions has been long recognized in many disciplines including HCI (e.g., (Ghinea and Ademoye, 2012; Willander and Larsson, 2007; Kaye, 2004; Murray et al., 2016)). Our sense of smell is often defined as an emotional system due to the shared brain areas (i.e., amygdala) involved in the processing of both smell and emotions (Warrenburg, 2005; Vernet-Maury et al., 1999). Smell has been shown to be particularly effective in priming emotional changes because the pleasantness (valence) of the scent is the primary dimension which impacts our initial emotional reaction (Delplanque et al., 2017).

The emotional feature design is similar to the intensity feature, however there are a few differences. The y-axis of the graph goes both in the positive and negative direction, and there are two graphs: one representing *valence* (i.e., perceived pleasantness versus unpleasantness of a scent), and the other for *arousal* (i.e., perceived calming versus arousing effect of a scent). The designer can specify each of the dimensions, with feedback showing how the

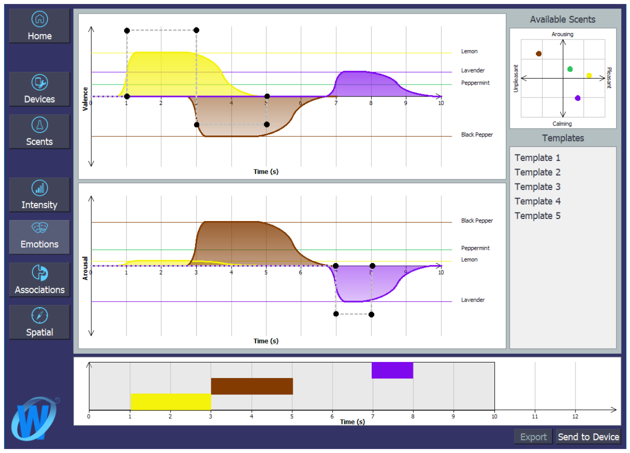

Figure 5: The GUI Emotions feature: The design tool with two timelines, the first timeline shows the design of valence, the second timeline shows the design of arousal, on the bottom the overview timeline.

changes of one influence the other (see Fig.5). Horizontal bars and the preview in the top right also show the emotional ratings of the available scents.

Persistent and repeated exposure to scents can induce affective habituation (Croy et al., 2013; Ferdenzi et al., 2014). For instance, repeated presentations of unpleasant scents reduce the emotional saliency (e.g., reduction of disgust) and vice versa (Croy et al., 2013). Akin to the intensity feature, the magnitude of the habituation effect can be addressed through adjusting the scent delivery timing and carefully sequencing and alternating scents.

A main design consideration regarding emotional reactions to scents is the subjective variability and individual differences based on past experiences and memories (Willander and Larsson, 2007; Ferdenzi et al., 2013). To account for personal preferences in OX design, the user profile (see *User Profile*) can store an individual's scent ratings and customise the scent database.

5.4. Associations Feature

Scents in nature are associated with the elements that are the source of the scent (e.g., 'banana' scent with banana fruit) (Kay, 2011). Scents convey meaning through such natural associations but scent associations can also be trained and learnt (Lawless and Engen, 1977). It has been shown, that those scent-associations affect the recall of target objects with the same accuracy as verbal, visual, tactile and auditory cues, however with a stronger connection to memories (Degel et al., 2001; Herz and Cupchik, 1995). In

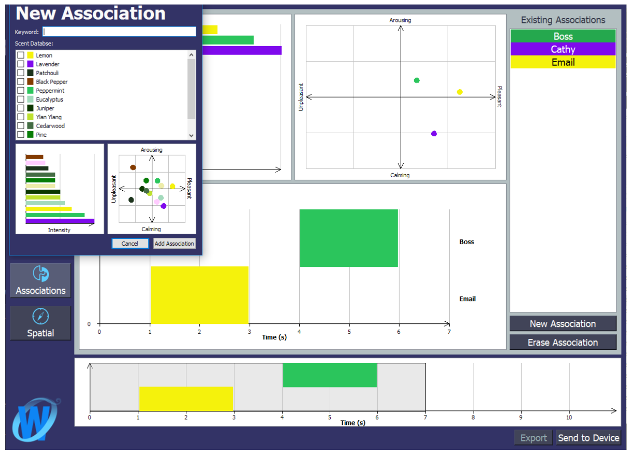

Figure 6: The GUI Association feature: The design tool with a timeline for specifying associations and duration, a list of defined associations, a summary of the intensity and emotional affects of the associated scents. *Top left*: The dialog box for creating and storing new associations.

other words, information recalled through olfactory cues can go further back in time. Hence, using scent-associations as interface elements can have a positive effect on users' performance (Lawless and Engen, 1977; Kaye, 2004; Maggioni et al., 2018; Patnaik et al., 2019).

In our GUI, designing using scent-associations is done on a one-dimensional graph, using a list of known associations and a tool for designing new associations (see Fig.6). The known associations can be dragged onto the graph and given a duration for which they should be perceived. When encountering a new association, the end user receiving the experience will need to select a scent which they deem appropriate and then begin a training process. This scent-association will then be integrated into their profile and be usable for future OXs.

The scent selected is at the discretion of the user of the toolkit, however, when designing a new association, it is possible to provide a set of recommendations for the scent selection (e.g., valence of a scent, being pleasant or unpleasant) as well as by accounting for individual preferences (e.g., alternative scents are suggested with similar emotional - valence and arousal - and intensity characteristics).

A main design consideration regarding the scent-association feature is the necessity of a training stage. To create meaningful scent-associations that perform over time a familiarisation / training stage (i.e., learning and testing)

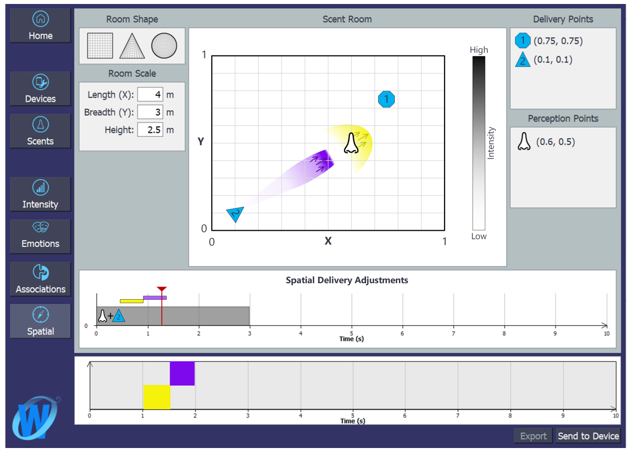

Figure 7: The GUI Spatial feature: The design tool with on the *left* the room settings, *middle* the canvas for designing the scented-area and positioning delivery or perception locations showing , *right* the list of delivery output locations and perception locations, *bottom* the delivery timeline with spatial time-window descriptions, showing the resulting temporal modifications.

is required. The training can be designed to impact the short or long-term memory, this affects the duration of the training and may be time consuming for the user (e.g., can require reinforcement training to impact the long-term memory) (Schab, 2014). A secondary concern is related to the memory span, a limited amount of learned scent associations can be effective at one time (Degel et al., 2001; Lehrner et al., 1999).

5.5. Spatial Feature

Similar to other environmental stimuli such as visual and auditory (Seibt et al., 2008), scent stimuli also have a spatial dimension, unless a scent is directly delivered to the user's nose (e.g., through a nose mask). Like sound, the source of a scent can be outside of a person's visual space (e.g., behind you) and can still be perceived and effectively localised (Porter et al., 2007). Jacobs et al. (2015) proved that humans, in the absence of any visual information, can navigate a given space through scent by following an olfactory grid — a map constructed from chemical stimuli. The perceived scent information can trigger us to change the path we walk (avoidance behaviour based on contextual factors (Rinaldi et al., 2017)) or bring our attention to a specific source (searching behaviour) (Rinaldi et al., 2017). In VR, for instance, directing a user's attention is frequently problematic because techniques are limited to the predominance of audio/visual information (Barfield and Danas, 1996). Hence, designing olfactory spatial cues can help to overcome those limitations.

We offer a simplified representation of the spatial complexity of scent stimulation using a two-dimensional space (see Fig.7). For spatial design information on the physical setup of the user's environment, including details such as room size and delivery output locations, is a requirement. As part of the user's profile, our GUI allows for the definition of a 2D scent-area, a list of delivery output points (coordinates within that space: x,y), and also a list of perception points (user position: x,y). For a scent area the dimensions and boundaries of the space (e.g., walls) can be described, and in the future other information could be included (e.g., obstacles or ambient air-flow). Each of the delivery output points has properties which describe the type of delivery, such as the volume of air created and flow direction.

When designing an OX using this tool a designer can use a timeline to specify time-windows with one of three descriptions: 1) a location of perception, 2) a pair of user location and delivery output location, or 3) a delivery output location and a delivery time advancement. These descriptions are used to filter (e.g., select the closest) delivery outputs and scents, and to calculate any required temporal offsets, a description of this process can be found in the section *Mapping Approach*.

For this first implementation, we limited the description of the scent-area to a set of three scalable shapes (i.e., square, triangle and circle) and we used a simplification of the air-flow simulation, importing a set of pre-defined delivery templates. The templates were the result of simulations using the AutoDesk CFD (e.g., different outputs, diameters, pressures etc.). By running Autodesk air-flow simulations, varying a range of parameters, we were able to create an initial database of reference points. Similarly to the scent database described in Section 4, here we tested various spatial parameters to provide designers with an initial set of options to design with. In the future, we aim to create an algorithm simulating the air-flow in function of the user input on their desired OX.

The main considerations in the design of the spatial OXs are the accuracy of the delivery and control of the environment. The ambient airflow of an environment strongly influences the delivery of scent and can positively reduce lingering or negatively reduce perception. This, and the fluctuant nature of airflow, make the spatial estimation of OXs rather difficult and best utilised in controlled environments.

5.6. Feature Interrelation

The final challenge when working with the features of OX design is their interrelation, modifying the desired intensity can require a different scent to be delivered, which in turn affects the emotional effect. We introduced two techniques to reduce unintended changes, the *first technique* is the ability to specify priority for each of the features. This allows an emotional description with higher priority than a simultaneous intensity description to be dominant (thus, changing the intensity will not modify the emotional output). The *second technique* is a graph (see Fig.4, caption) showing an overview of the outputs of the device(s). This graph begins at 0 seconds and shows at least the first 10 seconds (but can be extended), its purpose is to give users feedback about how/if the changes they make affect the output and can be seen at the bottom of each feature, it shows the periods of time for which scents should be perceived. This graph can also be used to change the time-frame that the design view is focused on (e.g., the time between 5s and 10s).

6. OWidgets Toolkit - Software Framework

After the GUI and design approach, the software framework defines the second main contribution of this paper, enabling the device-independent replication of OXs and providing a solution to two challenges of scent-based design (*C1* and *C2*). The framework consists of two core components: the *Mapper* (responsible for converting the desired OX description into a set of instructions) and the *Scheduler* (manages the dispatching of OXs and resolves conflicts between different OXs).

The framework provides an API with which the design GUI and other OX-creating applications can programmatically describe and submit their desired OXs. These OXs are mapped, scheduled, and are then communicated to the available devices through a uniform device interface (UDI). By using a uniform interface (described after the *Mapper* and *Scheduler*), our framework allows for the creation of an OX to be decoupled from a specific device, and thus facilitates device independence. The API also provides information on available scents and devices, allowing the design of OXs to adapt based on this information. The structure of the framework and the flow of this information can be seen in Fig.8.

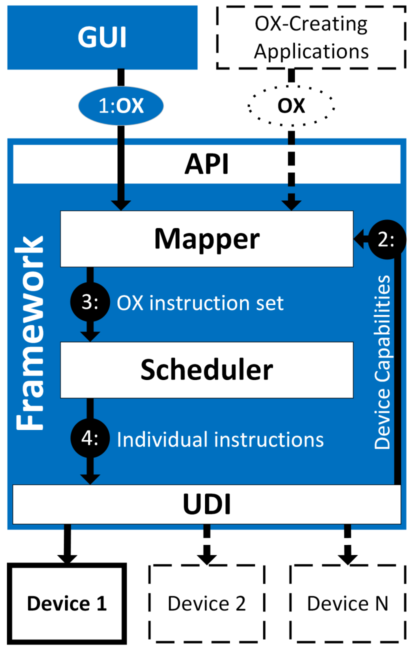

Figure 8: The OWidgets toolkit showing the flow of information. The GUI and other applications send OX descriptions (1) to the *Mapper*. The *Mapper* translates these into device instructions using the device capabilities (2), these instructions are wrapped into an instruction set (3) and are sent to the *scheduler*. The *Scheduler* sends the individual instructions (4) to devices using the Uniform Device Interface (UDI).

6.1. Mapper

The role of the *Mapper* is to translate from the desired OX into a set of device-controlling instructions. These instructions describe how to most accurately create the experience using the available delivery device(s). Here we first provide information on the inputs of this component and then describe the approach taken for the mapping process. The inputs to the *Mapper* are the (i) OX description and the three main influencers: (ii) the properties of the available scents, (iii) the capabilities of the available device(s), and (iv) the user's profile.

6.1.1. Olfactory Experience (OX) Descriptions

The desired OX is described by the four features of our GUI: Intensity, Emotions, Associations, and Spatial (see Fig.9). All the features change with respect to time and thus can be described by a list of points in time, with

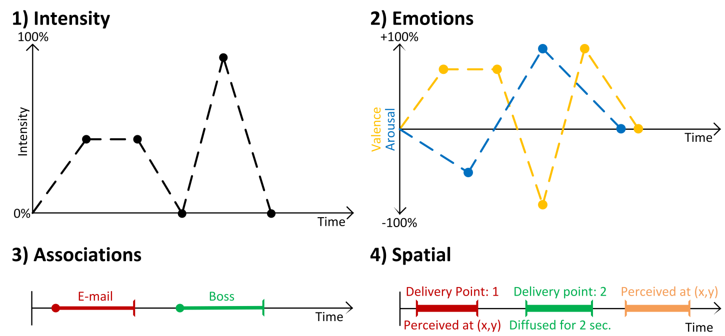

Figure 9: A visualisation of the data involved in the four feature descriptions: 1) Intensity, 2) Emotions, 3) Associations, 4) Spatial.

each point possessing additional data which describes the feature as shown below:

1) Intensity: A value between 0% and 100%
2) Emotions: Two-dimensional data (valence and arousal) with values between -100% and +100%
3) Associations: A string keyword or phrase linked to the associated information, paired with a duration
4) Spatial: A time-frame with either a perception location, a delivery location and diffusion time, or both perception, and delivery locations. Locations are described as coordinates; therefore, they can be mapped from one scent-room to another according to the user profile.

6.1.2. Scent Properties

In the same way that it is difficult for an artist to paint in colour if he cannot see his available paints, our framework cannot create meaningful OXs without knowing the properties of the scents that are available. This information (see *C3* in related work) defines the scope of creatable OXs and is the most influential part of the mapping process.

6.1.3. Scent-delivery Device Capabilities

As discussed previously (see *C2*), the capabilities of the SDDs are an important factor in the creation of OXs. This information is therefore included in the mapping process, adjusting the output towards the desired experience by accounting for the variation between devices. It is important to note that it may not be possible for a device to deliver exactly the desired OX, therefore the *Mapping Approach* creates the best-possible approximation. A parallelism of this would be printing a colour image using a greyscale printer.

A common set of device capabilities which are most relevant in the design of OXs, and are considered in our mapping, are:

- Delivery Method: Airflow (pressure, flow rate), natural diffusion, heating / evaporation
- Delivery Parameters: Direction, velocity, volume, relative intensity, contamination percentage, clean air channel, 3D delivery locations.
- Scent Information: Types of scents (powder, gel, liquid), number of scents, scent consumption rate.
- Device Capabilities: Scent mixing (none, ratio range), intensity regulation (none, through delivery), time performance (delay, recharge/pause, max duration).

6.1.4. User Profile

OXs as with any other user experience can be subjective, with variability between individuals (Firestein, 2001; Ferdenzi et al., 2013). To account for this, a user profile can be included into the mapping process, adjusting the output to cater for such idiosyncrasies and personalise the OXs to individual users. Each user's profile can be loaded into the framework and contains: (i) A list of overriding scent descriptions detailing the individual preferences of the user, (ii) A list containing all the user's trained scent-associations, and (iii) a description of the user's scent-area. These three items are used in the mapping process, (i) and (ii) adjust the scent's perceptual descriptions, and the scent-area description (iii) is used when processing spatial feature descriptions. Storing information related to users preferences and differences will allow the olfactory experience designer to select the scents that meet the users profile (similarly like a recommendation system).

The toolkit will in the future automatically suggest an alternative scent to be used based on the best approximation/similarity of scent descriptions (e.g., user Y does not like peppermint, so the toolkit will suggest the closest scent in function of the properties description, e.g., another arousing scent like lemon). One can imagine future extension with machine learning algorithms, that also evolve with changes in users' preferences. This will be particularly relevant when smell becomes a more common design tool for a wider audience.

6.1.5. Mapping Approach

We use an algorithmic approach to map the desired OXs as an approximation since creating a set of device instructions from an OX description is a complex challenge. This approach processes the timelines of each OX feature and merges them into a single timeline (see Fig.10, Step 1). This merge is done by creating time-segments in which all feature descriptions are constant or can be described by a constant function (see Fig.10, segment timeline). A time-segment is defined by a start, end time, and can hold a collection of feature description data. After this process, a new segment begins every time one of the feature descriptions change (see Fig.10, grey lines).

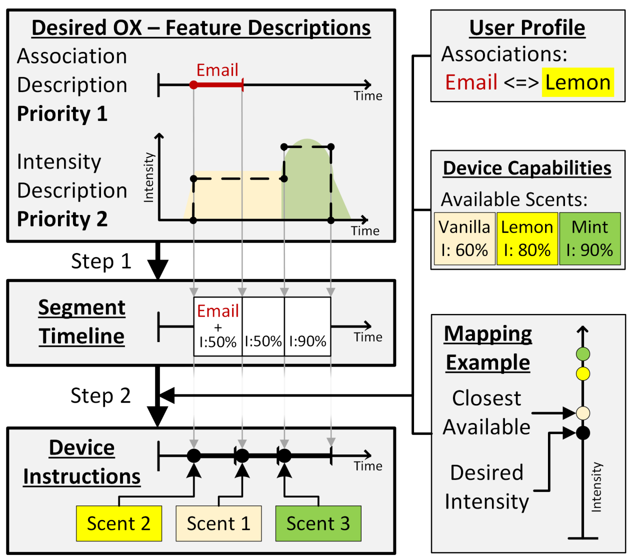

Figure 10: *Left*: The *Mapper* translates from an OX description into device instructions in 2 steps. Step 1: Merging desired OX feature descriptions into a segmented timeline. Step 2: The mapper processes this timeline and translates the segment descriptions into the appropriate scents and delivery parameters. *Right*: Two input examples for the *Mapper* (i.e., *user profile*, and combined *device capabilities* and *scent properties*), and an example of a scent selection based on intensity.

The segments of this merged timeline are then used to create the device instructions. Iterating along the segments of the timeline, we examine the descriptions of each segment and use them to select the most appropriate scent(s) and delivery parameters. These decisions are performed individually, first is the selection of scent, and then the calculation of delivery parameters. Both of these decisions require an order in which to process the descriptions and a method with which to resolve conflicting descriptions, for this the OX features each have a unique priority value. Without these priority values, the mapping process can become impossible when two descriptions require different scents/parameters but have equal importance.

Segments with Intensity, Emotion, or Association descriptions contain information which is used to directly filter and sort the available scents to determine the most appropriate selection (see Fig.10, mapping example). For the Intensity or Emotion descriptions the scents are sorted by their distance from the desired value, selecting thus the closest scent. The Association description is combined with the user profile to determine the required associated scent, this scent is then selected if available. Spatial information can also influence scent selection as it can filter the possible delivery locations, and some scents might not be available from a certain delivery output.

After the scent has been selected, the algorithm begins the calculation of delivery parameters based on the feature priorities and device capabilities. The Intensity description can be applied to the selected scent to calculate if the device can or should regulate the delivered intensity. The Emotion and Association descriptions could be used to determine mixing of scents, but exploration of this extra complexity is left for future work. The Spatial feature combined with the device capabilities are used to calculate the necessary temporal and delivery parameter modifications (e.g., advance delivery time, or increase delivery pressure) to ensure the OX is perceived at the desired time and space. This is done by simulating the scent delivery and calculating the time required for the scent to travel from the selected delivery location to the specified perception location. We approximate this simulation by using outputs and distances previously calculated by Autodesk CFD.

Once all the segments and their feature descriptions (e.g., Intensity, Emotions, Associations, Spatial) have been processed, the final stage of mapping approach is to convert the chosen scent and delivery parameters into device instructions. This means processing the timeline once more and outputting instructions reflecting each time there is a change of scent or delivery parameters. These instructions are encapsulated into an *OX instruction set* and are then sent to the *Scheduler*.

6.2. Scheduler

At the core of the *scheduler* is a process that triggers the dispatching of OX instructions at the desired time. However, when OXs overlap, their meanings can be lost or corrupted. Therefore, scheduling is important to resolve situations which can occur when multiple OXs are to be created, especially with simultaneous independent OX-creating applications (e.g., smell-based notification service while watching *Smell-O-Vision* movies).

With the term 'overlap' we refer to both physical overlapping (i.e., when the deliveries of scents interfere) and perceptual overlapping (e.g., lingering of scents, or reduced intensity due to habituation). To facilitate this scheduling, and to avoid modifying the meaning of the OXs, the delivery instructions created by the *Mapper* are encapsulated into an *OX instruction set*, and we schedule entire sets instead of their individual device instructions. Each of these sets contains the instructions needed to create a single OX. There are two scheduling problems to be solved by this layer, the first is the detection of conflicts — determining whether there is a physical or perceptual interference between sets — and the second is conflict resolution — adjusting the sets so that they no longer interfere, but without changing their meaning.

Detecting physical conflicts simply involves checking whether the time-frames or the deliveries of the two OXs are overlapping. However, to detect perceptual conflicts, the *scheduler* must record previous deliveries and can therefore account for effects such as lingering and habituation and adjust new instructions to counter them. By default, the *scheduler* uses an interval of 9s between OXs deliveries (Poellinger et al., 2001).

The conflict management logic contained in the *scheduler* aims to resolve conflicts in the most extensible way, and so, each OX carries information which describes the range of strategies with which it can be modified (without impacting its meaning). This information is described by a collection of Conflict Resolution Methods (CRM). Each type of CRM has their own parameters, for example a temporal shift of the OX can have maximum advancement and delay values. The way and order in which these CRMs are processed can be modified by overriding the toolkit's default logic.

6.3. Uniform Device Interface

In an attempt to tackle one of the challenges of scent-based design (see *C2*), our toolkit enables device-independent OX design by including the device properties into the OX mapping process as described previously. However, device control protocols still vary between producers (see *C1*), for the creation of OXs to also be device independent a uniform method for communicating with SDDs is needed. This is achieved by creating a generic interface for use with all devices — an interface which provides device information to our framework and lets the device receive our instructions.

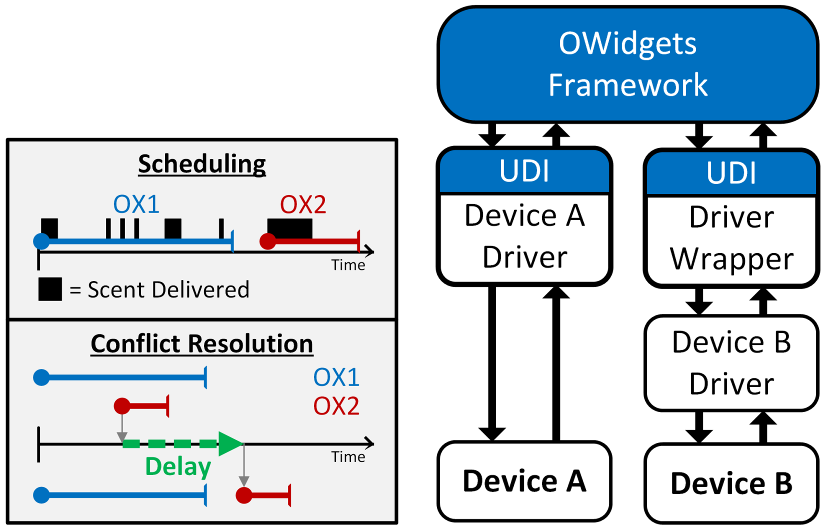

Figure 11: *Left*: The *scheduler* with an example showing the dispatching of instructions and conflict resolution between two OXs. *Right*: Framework communicating with devices, sending messages to device drivers through the UDI (Device A) or a driver wrapper (Device B).

The device information provided by this interface is a description of its capabilities (e.g., timing, delivery properties) and, if possible, it can also provide information about the available scents. The instructions system was designed to be extendable allowing for new instructions to be added as new devices are available and the SDD market develops. The instructions currently used by our *Mapper* describe the delivery of a scent by specifying an index and a duration in milliseconds. A second type of instruction we explored can either describe the desired state of the device or a set of changes in the state of the device (e.g., scent #1 turn on, intensity to 50%). These instructions can also be accompanied with a duration for which the changes should apply (e.g., intensity to 50% for 5 seconds). The uniform interface we propose can either be implemented directly into the device drivers by SDD manufacturers, or through a dedicated wrapper — adapting the device driver's interface to conform to the UDI (see Fig.11, right).

6.4. Toolkit Implementation

We chose to implement our software framework in C++ because of its accurate timing, portability between different operating systems, and its low-level system control (allowing us to interact easily with device drivers). This language is also compatible with the future toolkit extensions we envisioned (e.g., plugin for Unity and Adobe Suite). However, our choice of language (C++) is arbitrary and other languages could be used based on the requirements of the application context.

Our framework implementation runs as a stand-alone program and provides two interfaces. The first interface is used by OX-creating applications, such as the GUI, to describe and schedule the creation of OX. This communication occurs via local network ports and remote procedure calling, using UDP packets to communicate. The second interface is used to interface with SDDs through the UDI and connects to their driver DLLs which are detected at runtime.

We connected our toolkit to two devices, the first is an available research prototype SDD (Dmitrenko et al., 2017a) and the second is an AromaShooter device. We adapted our device's driver and created a wrapper for the AromaShooter API, both the device driver and wrapper connect to the toolkit by implementing the UDI and compiling to DLLs. Other SDDs can be used in the same way, communicating across language barriers through various means such as network ports.

7. Discussion and Implications

Toolkits aim to provide a constructive research foundation for "*producing understanding of an interactive artefact*" (Oulasvirta and Hornbæk, 2016). In this work, we contributed to a first foundation for smell-based experience design, we introduced OWidgets — a first device independent smell-based design toolkit for promoting explorations beyond audio-visual modalities. In the following sections, we discuss the specific challenges our toolkit is solving to enable smell-based experience design for a wide range of application scenarios. We then discuss two specific usage scenarios will illustrate the implementation potential of OWidgets. We particularly present insights from our efforts of implementing a smell-based notification system as well as creating more immersive virtual reality experiences augmented through smell.

7.1. Challenges Solved Through OWidgets

As stated in the related work, we identified three main challenges that motivated, and helped to identify key requirements for the development of a toolkit for smell-based experience design. Solving these challenges allowed us to achieve the aims which define the value of a toolkit for HCI (Ledo et al., 2018).

Challenge 1 and 3 — Limitations of software solutions for OX design and lack of a common language to describe OXs: We defined a set of OX design features, providing a common standard with which to describe OXs. Through these features, we achieved the aims of (i) reducing the complexity around smell-based experience design and thus the time required for designing with smell, and (ii) supporting the end users and providing guidance on the available design possibilities based on each of the features. By providing control of OX design features in the form of a GUI, and standard interfaces for device control for OX creation, we achieved the aim of (iii) empowering new audiences to experiment using the full capability of our sense of smell. These audiences can be a variety of end users, from developers that can code the OX experience directly using the framework, to creatives, artists, and designers that can simply use the GUI for OX design without requiring programming skills.

Challenge 1 and 2 — Device-independent design and replication of OXs: Since SDDs are developed as individual products, there was previously no uniform method of control. The toolkit we developed solves this challenge (see *C1*) and provides a device agnostic platform for scent delivery, allowing for easy switching between devices. However, due to the nature of scent delivery, the chosen device impacts the delivered experience — changing to a different device results in a modified experience (see *C2*). Our framework solves this challenge through accounting for the device capabilities when mapping the OX into device instructions, decoupling the experience from the device/context and enabling the replication of OXs beyond one-off applications. Therefore we achieved the aim of (iv) enabling both the replication of OXs and the potential creative exploration around smell-based experience design.

7.2. Usage Scenarios

As discussed in a recent HCI work (Ledo et al., 2018), a systematic evaluation of a toolkit is a necessary step. The evaluation goes beyond the aims of this paper. We acknowledge the importance of demonstrating the values of a toolkit and evaluate its use. Hence here we present two usage scenarios by discussing the impact of applying our toolkit. For this exploration we selected two applications that have been explored within HCI: smell-based notifications and immersive Virtual Reality experiences. It is worth noting that the first usage scenario has recently been published by Maggioni et al. (2018) providing details on the implementation and design process. Moreover, the second usage scenario is inspired by a recent collaboration with a creative company (New Reality LtD, New York) who are active creators of multisensory VR contnet.

7.2.1. Smell-Based Notifications

Using scent as a notification modality has already been explored in prior HCI research, acknowledging its potentials as an alternative interaction modality (e.g., (Maggioni et al., 2018; Arroyo et al., 2002; Bodnar et al., 2004; Warnock et al., 2011)). However, these works identified two main issues during the implementation of smell-based notifications for which our toolkit can provide solutions: *controllability and accuracy of the scent delivery*, and *individual scent preferences*. These issues were compromising the effectiveness of scent as medium and blocking any possible implementation of smell-based notifications in a real-world usage.

Controllability and accuracy of the scent delivery (compared to audio or visual notifications) is mainly connected to the capabilities of the SDDs used (e.g., regular fans with directional funnels (Bodnar et al., 2004), atomizers (Arroyo et al., 2002)). OWidgets uses these capabilities and adjusts the final experience to account for them. Our software framework includes the physical delivery capabilities into the *Mapper*'s process, and can adjust the delivery start times and durations to avoid cross contamination between separate scent notifications by estimating the scent lingering. As real-time messages are event-driven and unpredictable, a big challenge in a real-world usage is olfactory overload (e.g., when multiple messages arrive within a short timeframe). The *scheduler* component of our framework can account for these occurrences through tracking of OXs and conflict resolution (see *Scheduler*). OXs can then be delayed, shortened, or cancelled to resolve their interference with one another OX based on various measures (e.g., priority, or time since the event). The OX-creating application (e.g., messaging application) can also avoid this overlapping by deciding when to deliver OXs (e.g., messages defined as urgent). However, the *scheduler* is necessary when combining OX-creating applications (e.g., smell-based notifications while watching *Smell-O-Vision* movies).

Individual scent preferences are shown to highly impact the performance of scent as a medium (Warnock et al., 2011; Bodnar et al., 2004). The individual variabilities and preferences (Ghinea and Ademoye, 2012; Ferdenzi et al., 2013) are indeed one of the major concerns in introducing smell-based interaction in HCI. Our toolkit allows for the creation of a *user profile* containing individual preferences and storing the created associations. As a result, OXs designed through the Association feature can thus be shared between multiple users, using their individual profiles to map from the associated information to the associated scent. This reusability of OX descriptions can facilitate future growth towards the concept of reusable modular components for olfactory interfaces. Providing the possibility for users to customize smell-based notifications to match their preferences can increase the effectiveness of the sense of smell as a medium and tackle the challenge of unfamiliarity. Furthermore, we demonstrated that training users scent-associations in a smell-based notification system improves users' confidence and performance (see Maggioni et al. (2018) for more details on the study results but also on the implementation of a smell-based notification system).

7.2.2. Immersive Virtual Reality Experiences

Virtual Reality (VR) environments are increasingly used to simulate natural events and social interaction (Bohil et al., 2011). VR is indeed described as an effective medium for conveying emotions (Riva et al., 2007), but in HCI the VR domain has been restricted to the audio-visual and more recently haptic technologies, leaving smell-based interactions almost unexplored (e.g., (Ranasinghe et al., 2018b)). The few works that used scents in VR aimed to increase the sense of presence (Jones and Dawkins, 2018) or augment/enhance the everyday experiences (e.g., (Li and Bailenson, 2018; Narumi et al., 2010)). However, these works identified two main challenges in the implementation of immersive VR experiences, for which our toolkit can provide solutions: *controllability and accuracy of the scent delivery* and *limited design possibilities for smell-based experiences.*

Controllability and accuracy of the scent delivery. The main issue highlighted in these works is connected with the design of the scent delivery and its controllability in terms of timing (e.g., latency, lingering etc.) and perceivability (e.g., perceived intensity). The SDDs used in VR are usually attached to a head mounted display (HMD) (Ranasinghe et al., 2018b; Patnaik et al., 2019) or in other cases the scent delivery is a physical source of scent positioned close to the user's periphery (e.g., a scented cotton bud attached to the HMD Li and Bailenson (2018) or a wearable device around the neck (Amores and Maes, 2017)). The scent delivery output is positioned to account for all examples of SDDs capabilities on the HMD or close to the nose, reducing latency, increasing perceivability, and minimising lingering. The OWidgets framework includes the SDDs capabilities and physical delivery parameters into the *Mapping Approach*, adjusting the scent delivery to match the desired experience. With the GUI's Spatial feature it is possible to simulate the delivery trajectory and estimate the time taken for the user to perceivieve the scent. Making use of this feature can facilitate accurate delivery of scent within the VR area, removing the requirement for SDDs attached to the HMD.

Limited design possibilities for smell-based experiences. Exploiting the GUI Features, mainly Spatial and Emotions, developers and designers of VR environments can create OXs that are accurate in time and space as well as ensuring their replicability. Smell-based interaction in VR designed through the support of our toolkit can empower the creation of emotional connoted OXs along a timeline using the OXs as a new storytelling layer (e.g., orienting the attention of the users).

In summary, the above two usage scenarios provide a starting point for the toolkit evaluation. However a more formalised validation is required in future work. For this purpose different evaluation methods, such as individual or multiple instances (e.g., case studies), usability test (e.g., PSSUQ (Lewis, 1992)), user feedback (e.g., focus groups, workshops and hackathon days), technical performance (e.g., more detailed benchmark comparisons), heuristics (e.g., Olsens's heuristics) can be used (Ledo et al., 2018). The evaluation feedback will benefit the improvement of the toolkit in each of its parts, proving how our toolkit enables creativity and exploration in real-world environments. We are currently working with various content creators and creative industries in order to test the use of our toolkit in a real world context (e.g., with New Reality LtD in NYC) and to gain additional insights on future extensions of our design toolkit.

7.3. Remaining Challenges and Future Extensions

While our toolkit solution overcomes the key challenges in OX design, there are still possibilities for improvements. Here we discuss remaining challenges and future extension opportunities.

For example, our definition of measurable features in OX design is not a comprehensive and ultimate solution, but a necessary first step in quantifying OXs for their replication. The mapping of scent properties remains an open challenge, and we are far from defining a set of "basic scents" or a "scent RGB". More research is needed to establish a larger database accounting for more scent proprieties. The mapping between emotional reactions and scents, following the standardised SAM measurement (Bradley and Lang, 1994), is a first mapping than can and need to be extended in the future covering many other OX experiential descriptors. Our OX mapping can be extended by including new features (e.g., adding dimensions to our scent database) or new classification/mapping methods (e.g., mapping chemical components) such as a mathematical modelling approach (e.g., (Keller et al., 2017)).Our toolkit is designed to be scalable, allowing for the easy addition of new scents, new devices, and future extensions. From a perceptual perspective, the individual sensitivities are an open challenge. A future extension of the toolkit could include an assessment of the sensitivities of each user (e.g., (Hsieh et al., 2017)) and store the information in the *User Profile*. The Spatial feature and estimation of the OX perception can be improved by using more advanced scent delivery simulations inside the *Mapper*, such as algorithms for computational flow dynamics.

As highlighted in Ledo's review work (Ledo et al., 2018), one of the goals of building a new toolkit is to integrate it with current practices and infrastructures, matching and aligning the toolkit with existing standards. Pursuing the goal of extending the audio-visual dominated interaction space, we envisage future toolkit extensions, such as the creation of specific plugins for existing third-party development environments such as Unity and Adobe Premiere. Plugins for the Adobe suite are developed in C++ so forming the connection with our implementation of OWidgets is straightforward, this could allow the integration of OXs in audio and visual content creation (e.g., clips, movies, or photos). Moreover, Unity uses C# can import C-style functions so a simple wrapper can be created around the API of our toolkit to allow this. This could be extended to allow for the spatial representation of OXs within VR and provide synchronised multisensory information, in the creation of VR content (e.g., games, training etc.). In the future, developments of our toolkit could include a cloud-based solution, allowing collaborative creation of scent-based experiences. These extensions would allow OX design to flourish and become accessible to a wide range of users.

8. Conclusion

We introduced OWidgets, a toolkit to enable the design of olfactory experiences (OXs). Unlike other interaction modalities, such as vision and audio, the sense of smell is under-used in HCI despite being acknowledged as a powerful modality. OWidgets reduces the complexity of smell in the design of interactive systems and guides design explorations based on clear design features, suggesting pre-defined paths (e.g., scents database, templates) and rules (e.g., conflict resolution). Through those toolkit characteristics, new audiences (e.g., developers, artists, designers) are empowered to use and experiment with smell-based interaction design. Overall, this formalisation of OX design enables the replication of OXs beyond one-off applications and helps to growth the field. Future extensions in form of plug-ins will foster the opportunities to extend and integrate the toolkit into the wider audio-visual ecosystem.

9. Acknowledgements

This project has been funded by the European Research Council (ERC) under the European Unions Horizon 2020 research and innovation program under Grant No.: 638605 and No.: 737576.

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